Simulations of Forced Isotropic Compressible Turbulence

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Compressible turbulent flows arise in many science and engineering applications, including conventional gas engines, supersonic combustion ramjet engines, and astrophysical jets, and are also important for many laboratory applications. Many phenomena in compressible turbulence are currently poorly understood compared with incompressible turbulence: the mechanism for energy transfer, interaction among scales and universality, intermittency, and the effects of compressibility on the turbulent energy spectrum. Of particular interest are shocklets, which are short-lived, localized shocks produced by the fluctuating fields of the turbulent eddies [1]. Shocklets convert turbulent kinetic energy to internal energy via the pressure-dilatation correlation, and increase kinetic energy decay through dilatational dissipation (dilatation is the compressible component of the velocity).

We use direct numerical simulations (DNS) to simulate compressible forced isotropic turbulence and to quantify the effects of compressibility in turbulent flows [2]. DNS resolves all scales down to the viscous dissipation range, but on today's computers is restricted to small, idealized domains. As DNS offers a wealth of information inaccessible in laboratory experiments, statistics from DNS studies are critical to parameterize turbulence models, e.g., unclosed terms in Reynolds-averaged Navier-Stokes (RANS) and moment closures or subgrid stresses in large eddy simulations (LES).

Isotropic turbulence simulations are traditionally forced at the smallest wavenumber using spectral numerical methods. We have implemented a new forcing technique that is efficient for (nonspectral) compact finite difference numerical methods [3]. The successful implementation of this physical-space forcing is critical for the efficient use of large computer platforms like Roadrunner, where communications among thousands of nodes impose important computational challenges. The standard domain is a 3D periodic box (Fig. 1). Production runs are being started with resolutions of 1024^3 and higher. The effects of compressibility become more significant with increasing rms Mach number (the ratio of the root-mean-squared fluctuating velocity to the speed of sound (Fig. 2). Of particular interest is the influence of the equations of state (both pressure and caloric) on the turbulence

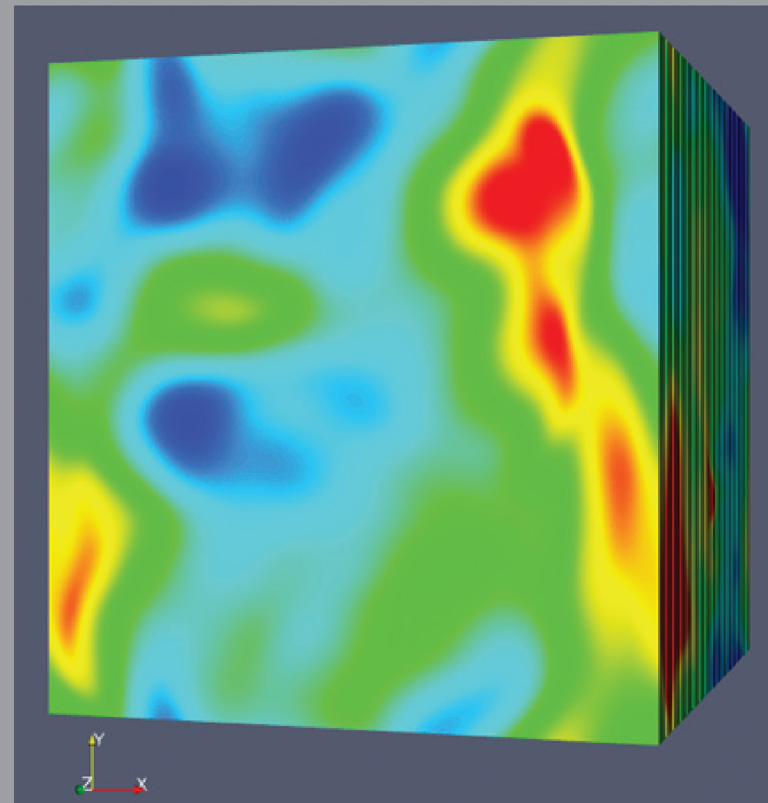

Fig. 1. Pressure in a forced isotropic compressible turbulence simulation. Compressible turbulence is characterized by regions with large pressure gradients where shocklets may develop.

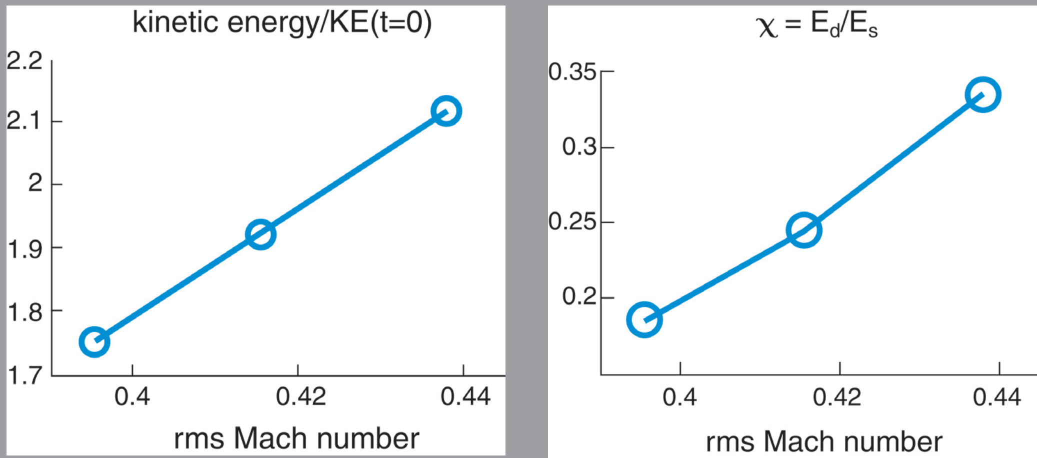

Fig. 2. Statistics that vary with the Mach number show how increased compressibility affects the simulation. The equilibrium averaged values of kinetic energy (left) and dilatational energy (right) increase with Mach number. Here E_d is the energy in the dilatational (compressible) velocity component, and E_s is that in the solonoidal (incompressible) component.

properties, never considered before, but important in laboratory applications. Statistics collected from high-resolution turbulence simulations will quantify the energetic effects of compressibility and shocklets. These simulations also produce the turbulent inlet condition for simulations of turbulence-shock wave interaction [4].

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